The Pomeron Structure and Diffractive Parton Distributions

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Abstract. Measurements of the diffractive structure function, F_2^D, of the proton at HERA are used to extract the partonic structure of the Pomeron. Regge Factorization is tested and is found to describe well the existing data within the selected kinematic range. The analysis is based on the next to leading order QCD evolution equations. The results obtained from various data sets are compared. An analysis of the uncertainties in determining the parton distributions is provided. The probability of diffraction is calculated using the obtained results.

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INTRODUCTION

In the last 10 years a large amount of diffractive data was accumulated at the HERA collider [1, 2, 3]. There are three methods used at HERA to select diffractive events. One uses the Leading Proton Spectrometer (LPS) [3] to detect the scattered proton and by choosing the kinematic region where the scattered proton looses very little of its initial longitudinal energy, it ensures that the event was diffractive. A second method [2] simply requests a large rapidity gap (LRG) in the event and fits the data to contributions coming from Pomeron and Reggeon exchange. The third method [1] relies on the distribution of the mass of the hadronic system seen in the detector, M_X, to isolate diffractive events and makes use of the Forward Plug Calorimeter (FPC) to maximize the phase space coverage. We will refer to these three as ZEUS LPS, H1 and ZUES FPC methods.

The experiments [4, 5, 6] provide sets of results for inclusive diffractive structure function, $x_{I\!P}F_2^{D(3)}$, in different regions of phase space. In extracting the initial Pomeron parton distribution functions (pdfs), the data are fitted assuming the validity of Regge factorization.

In the present study, Regge factorization is tested. New fits, based on a NLO QCD analysis, are provided and include the contribution of the longitudinal structure function. The obtained PDFs are systematically analyzed. A comparison of the different experimental data sets is provided. Additional quantities derived from the fit results are also presented.

In order to make sure that diffractive processes are selected, a cut of $x_{I\!P} < 0.01$ was

[1] also at Max Planck Institute, Munich, Germany, Alexander von Humboldt Research Award.

performed, where $x_{I\!P}$ is the fraction of the proton momentum carried by the Pomeron. It was shown [7] that this cuts ensures the dominance of Pomeron exchange. In addition, a cut of $Q^2 > 3$ GeV^2 was performed on the exchanged photon virtuality for applying the NLO analysis. Finally, a cut on $M_X > 2$ GeV was used so as to exclude the light vector meson production.

REGGE FACTORIZATION

The Regge Factorization assumption can be reduced to the following,

$$F_2^{D(4)}(x_{I\!P}, t, \beta, Q^2) \quad = \quad f(x_{I\!P}, t) \cdot F(\beta, Q^2), \tag{1}$$

where $f(x_{I\!P}, t)$ represents the Pomeron flux which is assumed to be independent of β and Q^2 and $F(\beta, Q^2)$ represents the Pomeron structure and is β and Q^2 dependent. In order to test this assumption, we check whether the flux $f(x_{I\!P}, t)$ is indeed independent of β and Q^2 on the basis of the available experimental data.

The flux is assumed to have a form $\sim x_{I\!P}^{-A}$ (after integrating over t which is not measured in the data) . A fit of this form to the data was performed in different Q^2 intervals, for the whole β range, and for different β intervals for the whole Q^2 range.

Figure 1 shows the Q^2 dependence of the exponent A for all three data sets, with the $x_{I\!P}$ and M_X cuts as described in the introduction. The H1 and the LPS data show no Q^2 dependence. The ZEUS FPC data show a small increase in A at the higher Q^2 region. It

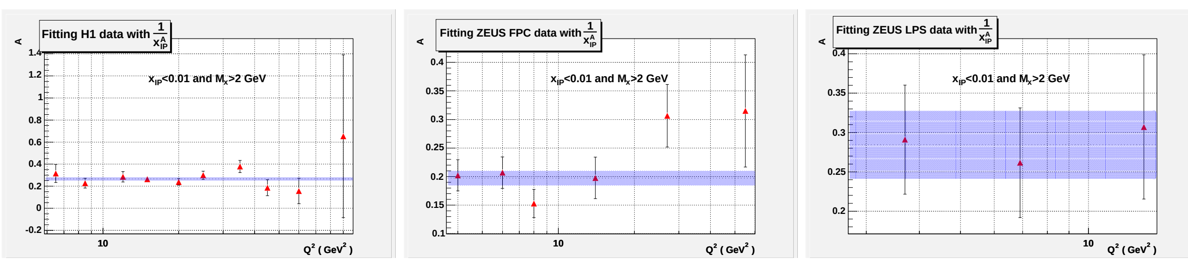

FIGURE 1. A as a function of Q^2 for $x_{I\!P} < 0.001$ and $M_X > 2$ GeV, for the three data sets, as indicated in the figure. The line corresponds to a fit over the whole Q^2 region

should be noted that while for the H1 and LPS data, releasing the $x_{I\!P}$ cut to 0.03 seems to have no effect, the deviation of the ZEUS FPC data from a flat dependence increases from a 2.4 standard deviation (s.d.) to a 4.2 s.d. effect (not shown).

The β dependence of A is shown in figure 2. All three data sets seem to show no β dependence, within the errors of the data. Note however, that by releasing the $x_{I\!P}$ cut to higher values, a strong dependence of the flux on β is observed (not shown).

We thus conclude that for $x_{I\!P} < 0.01$, the Pomeron flux seems to be independent of Q^2 and of β and thus the Regge factorization hypothesis holds.

NLO QCD FITS

We parameterized the parton distribution functions of the Pomeron at $Q_0^2 = 3$ GeV^2 in a simple form of $Ax^b(1-x)^c$ for u and d quarks (and anti-quarks) and set all other quarks

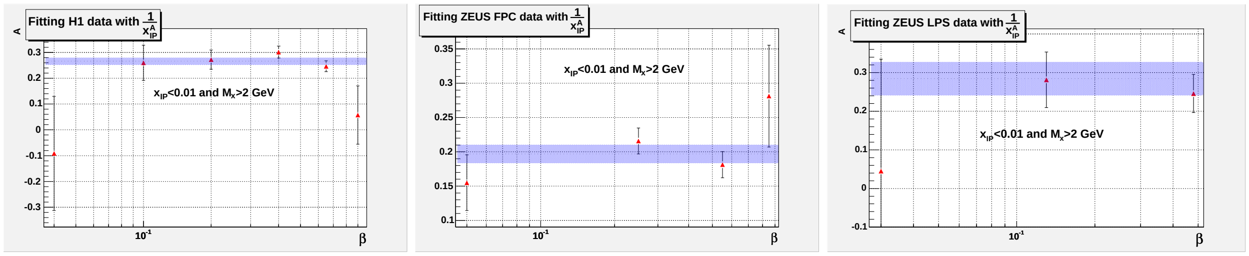

FIGURE 2. A as a function of β for $x_{I\!P} < 0.001$ and $M_X > 2$ GeV, for the three data sets, as indicated in the figure. The line corresponds to a fit over the whole β region

to zero at the initial scale. The gluon distribution was also assumed to have the same mathematical form. We thus had 3 parameters for quarks, 3 for gluons and an additional parameter for the flux, expressed in terms of the Pomeron intercept $\alpha_{I\!P}(0)$. Each data set was fitted to 7 parameters and a good fit was achieved for each. The H1 and ZEUS FPC had $\chi^2/\mathrm{df} \approx 1$, while for the LPS data, the obtained value was 0.5. The data together with the results of the fits are shown in figure 3. The following values were obtained for $\alpha_{I\!P}(0)$,

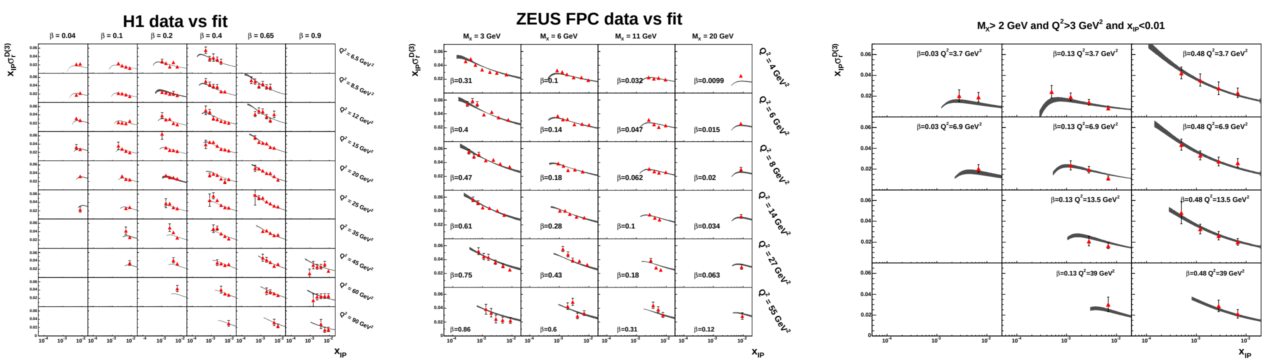

FIGURE 3. The diffractive reduced cross section of the proton multiplies by $x_{I\!P}$, as a function of $x_{I\!P}$ for the different data sets (the most right plot is for the LPS data) in different bins of Q^2 and β, as indicated in the figure. The bands are the results of the fits including uncertainties.

for each of the three data sets: $\alpha_{I\!P}(0) = 1.138 \pm 0.011$, for the ZEUS FPC data, $\alpha_{I\!P}(0) = 1.189 \pm 0.020$, for the ZEUS LPS data, $\alpha_{I\!P}(0) = 1.178 \pm 0.007$, for the H1 data.

The parton distribution functions are shown in figure 4 for the H1 and the ZEUS FPC data points. Because of the limited β range covered by the LPS data, the resulting pdfs uncertainties are large and are not shown here. For the H1 fit one sees the dominance of the gluons in all the β range. For the ZEUS FPC data, the quark constituent of the Pomeron dominates at high β while gluons dominate at low β. We can quantify this by calculating the Pomeron momentum carried by the gluons. Using the fit results one gets for the H1 data 80-90%. while for the ZEUS FPC data, 55-65%.

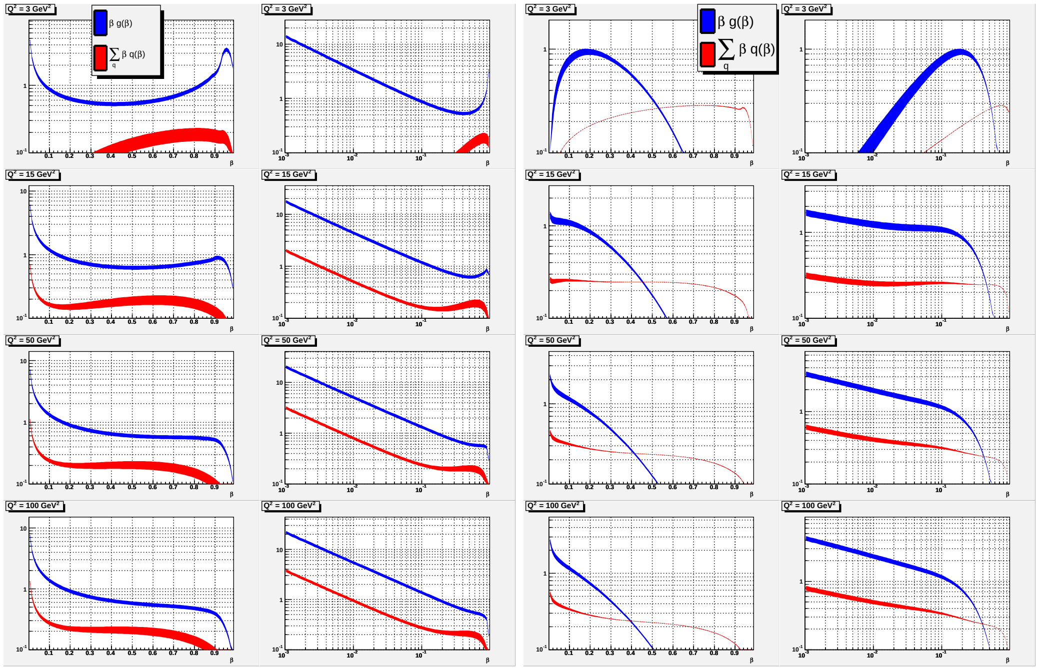

FIGURE 4. Quark and gluon pdfs of the Pomeron as obtained from the H1 data fit (left two figures) and from the ZEUS FPC data fit (two rightmost figures) as a function of β, at different values of Q^2.

COMPARISON OF THE DATA SETS

One way of checking the compatibility of all three data sets is to make an overall fit for the whole data sample. Since the coverage of the β range in the LPS data is limited, we compare only the H1 and the ZEUS PC data. A fit with a relative overall scaling factor of the two data sets failed. Using the fit results of one data sets superimposed on the other shows that the fit can describe some kinematic regions, while failing in other bins. This leads to the conclusion that there seems to be some incompatibility between the two data sets.

PROBABILITY OF DIFFRACTION

It is of interest to calculate the probability that a certain parton is produced in a diffractive process [8]. The probability of diffraction on quarks and gluons, as a function of Bjorken x at different values of Q^2 are shown in figure 5, using the results of the H1 and the ZEUS FPC data fits. The ZEUS FPC data shows that throughout the whole kinematic range shown in the figures, the probability for diffraction is not bigger than 0.15, far from the Pumplin [9] limit of 0.5. This is not the case for the H1 data for which, at small x and low Q^2, the probability of diffraction induced by gluons becomes greater than 0.5 and thus unphysical. Note however that the results for $x < 2 \cdot 10^{-4}$ are in a region where H1 has no data and thus the calculated probability in this region is an extrapolation based on the fit parameters. In order to get physical results, some process, like saturation, must

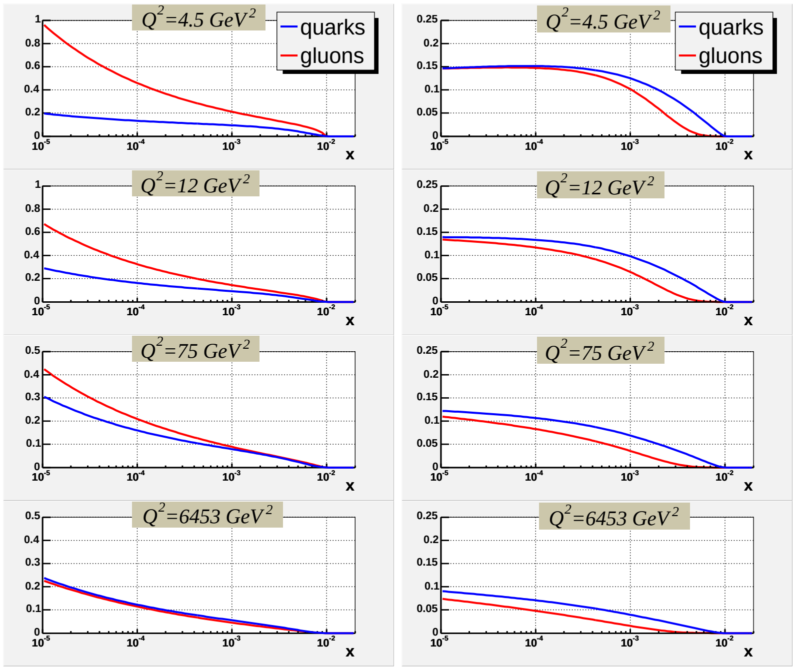

FIGURE 5. Probability of diffraction as a function of x, at different values of Q^2, calculated from the results of the H1 data fit (left figure) and from those of the ZEUS FPC data fit (right figure).

lower the expected value.

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